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Modeling Air-to-Air Visual Search

by

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and

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Weapons Development Department

OCTOBER 1974

Naval Weapons Center
CHINA LAKE, CALIFORNIA 93555

Naval Weapons Center

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FOREWORD

The Naval Air Systems Command is sponsoring the advanced development of a short-range air-to-air missile system at the Naval Weapons Center (NWC), China Lake, Calif. This system, identified as Agile (Task Assignment A-30303/216-1/W16-25000), is specifically designed for visual short-range engagements. Human factors analyses are part of the effort being made toward the development of the Agile missile system. This report documents some of the analysis performed to quantify the visual detection performance of aircrewmen.

This report has been reviewed for technical accuracy by P. B. Homer. It is released at the working level for information only.

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(U) This report provides background information required by the analyst who is engaged in modeling air-to-air visual detection performance by aircrewmen. The type of data required in systems and operations analysis is described and methods of obtaining the data are discussed.

(U) The methods used to gather much laboratory data are described, and the hazards in using this data as input for mathematical models are discussed. A model is also described to illustrate the modeling process.

CONTENTS

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INTRODUCTION

The development of new aircraft, weapons systems, and tactics requires knowledge of aircrewman performance and limitations. One of the performance estimates required in analysis of air-to-air combat is the range at which other aircraft are visually detected by a pilot or other aircrewman. The methodology used in obtaining such estimates ranges from actual flight tests to mathematical modeling. The latter process is popular because of the lower cost and ease of obtaining "data."

There are, however, hazards in modeling human visual performance that sometimes are not known by mathematicians or systems analysts. This report discusses visual detection data requirements and the limitations to the methods of obtaining these data. A model is also described, as an illustration of the modeling process. The report is intended to provide background information to those working in the quantification of human visual performance in air-to-air environments.

USE OF VISUAL DETECTION DATA

This section discusses some concepts of the description of visual aircraft detection performance by aircrewmen. Visual detection performance and the accuracy in describing this performance are discussed and related to the analysis required for weapon system specification. Guidelines are recommended for obtaining a description of visual detection as required by air combat maneuvering analyses.

MEASURES

Three important measures used to describe visual detection performance in airborne situations are (a) range and angular coordinates of the target at detection, (b) probability of detection, and (c) false reports (i.e., no target was present when a report was made). The basic data can be generated experimentally by exactly repeating a given situation a number of times (same pilot and same environment). A distribution of the pilot's reports can be drawn (Figure 1), and plotted cumulatively (Figure 2).

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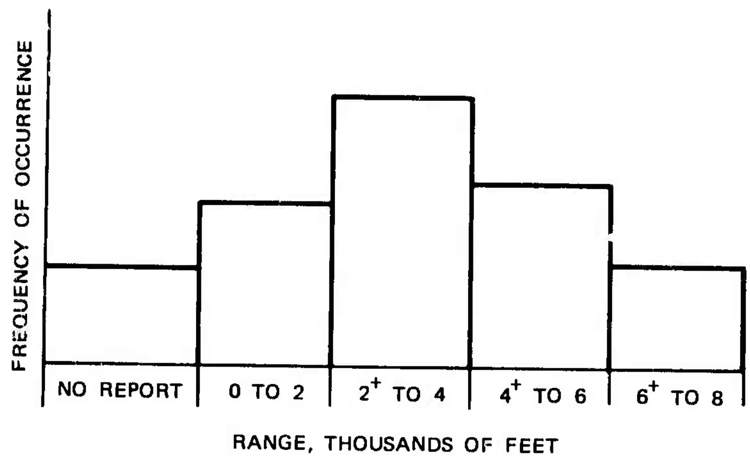

FIGURE 1. Distribution of the Range at Which an Aircraft Is Sighted for a Specific Environmental Situation.

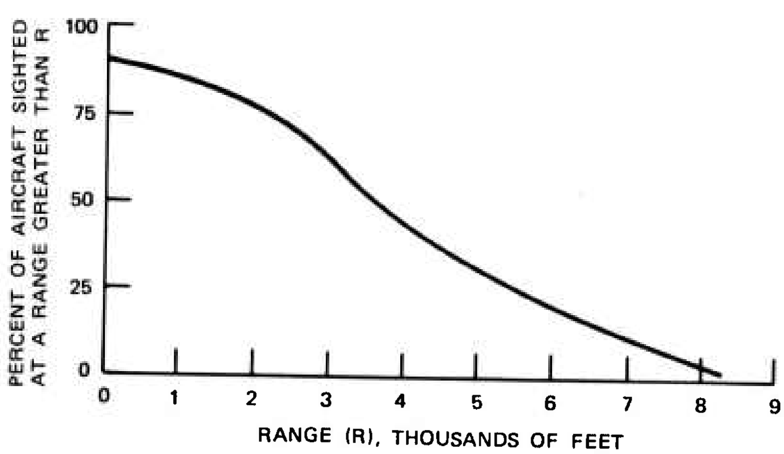

FIGURE 2. Normalized Cumulative Plot of the Distribution in Sighting Ranges shown in Figure 1. This figure is usually called the cumulative percentage of detection as a function of range.

The ranges shown in Figure 1 may be detection, recognition, or identification range. These words are best defined by a description of the briefing given to the pilot. *Example* definitions follow:

At detection--the pilot reports that he sees an object in the air that is not a meteorological phenomenon (e.g., not a cloud).

At recognition--the pilot reports that the object is a fixed-wing aircraft.

At first identification level--the pilot reports that the aircraft is a small jet.

At second identification level--the pilot reports that the aircraft is an F-4.

The perceptions associated with these different kinds of reports may be separated in time or in range, or they may occur simultaneously. When the report is made, some level of confidence is associated with it. This level of confidence can be manipulated to some extent by the briefing or by informal competition among subjects.

LABORATORY DATA

Analysts frequently use laboratory data as a basis for extrapolation to the real world. Few of them really take a hard look at the conditions under which the data were collected. However, a comparison of the conditions in the laboratory and in the real world is necessary, to aid in assessing the applicability of the laboratory data to the real world.

The type of data generated ranges from the simulation of an actual operational situation to the conduct of strictly psychophysical experiments with few real-world conditions included. The former is sometimes called applied research; the latter, basic research. The spectrum from simulation (which may include flight testing) to psychophysical experiments is a continuous one; control over the variables increases as the psychophysical experiment is approached, but applicability to the real world decreases. The usefulness of these different kinds of test results is discussed elsewhere.[1,2] The following discussion is concerned principally with data from laboratory psychophysical experiments, because it has been used extensively in visual detection models.

[1] Chapanis, A. "The Relevance of Laboratory Studies to Practical Situations," ERGONOMICS, Vol. 10, No. 5 (1967), pp. 557-577.

[2] Teichner, Warren H. "Human Factors/Ergonomics: Conceptions and Misconceptions," HUM FACTORS, Vol. XIV, No. 8 (August 1971), pp. 10-12.

Laboratory data of possible application to the modeling of the aircraft sighting process have been collected with (1) no visual search required (and the target presented both on and off the point of fixation), (2) visual search in an empty or homogeneous field, and (3) visual search in a structured or cluttered field. Most of these experiments use a time limit and/or a forced-choice procedure, or can include free search with the opportunity of errors of omission or commission. In forced choice, the subjects must give an answer as to where (e.g., which sector) or when (e.g., which time interval) the target was presented. In most of these tests, abstention is not allowed; that is, "I don't know" or "I didn't see anything" are not in the choices. If the subjects are not sure, they must guess at an answer.

Experimenters prefer forced choice because the data have less variability. Such data can be summarized in the format shown in Figure 3. Only five discrete sizes were tested in this hypothetical experiment. However, it would usually be assumed that performance varies *continuously* with target size.

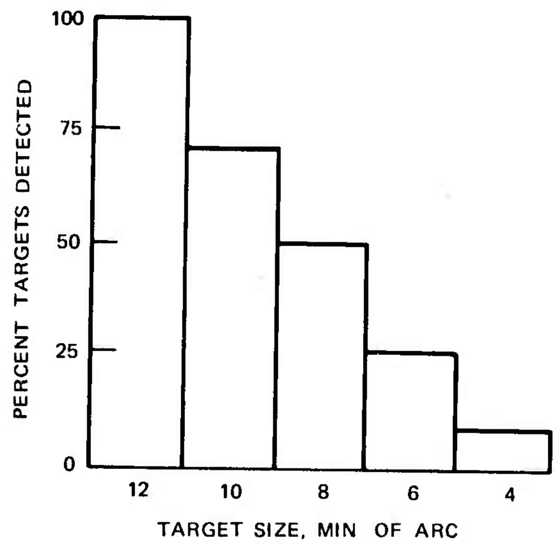

FIGURE 3. Data Format for Detection of Targets of Variable Size (With All Other Characteristics Held Constant).

In this hypothetical experiment, each target size was presented the same number of times to a number of observers. It is seen that, every time a target subtending 12 min of arc was presented, its location was correctly reported. Ten percent of the 4-min-of-arc target locations were correctly reported.

If forced choice is used in the experiment, the subjects will get some answers right regardless of whether or not the target is *perceived*. To take this into account, the scores for guessing are sometimes corrected by the equation

$$S = \%\ \text{right} - \frac{\%\ \text{wrong}}{N - 1} \tag{1}$$

where

S = % right, corrected for guessing

N = number of alternatives (choices) the subject has in responding.

It should be pointed out that this correction for guessing may have no significance or may not fit the assumptions behind some mathematical models.[3]

The data in Figure 3 can be corrected for guessing if it is assumed that there are ten equally difficult alternatives for each response (Figure 4). If it is assumed that the response process is *continuous* with target size, the data also can be smoothed (Figure 5).

Figure 5 appears to be similar to Figure 2, with total percent of samples equivalent to percent targets detected, and range corresponding to target size. It is common practice to use Figure 5 type data as an estimator of the required Figure 2 data. However, these curves are *not* equivalent, the key reason being that Figure 2 is derived from a free search, no-time-limit, call-it-when-you-see-it type situation. *All* the sightings are reported voluntarily with an unknown, but probably high, confidence level. The data in Figure 5 are forced-choice in a restrictive situation; the percent targets detected probably correspond to the confidence level (which is variable down to zero).

The curve in Figure 5 represents performance under one set of conditions for targets of different sizes. A large number of such curves are produced in an experiment where several parameters are varied. These are usually summarized by picking one point off each curve (the dotted line in Figure 5) to use as an indicator of performance. The rationale for this is:

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[3] Office of Naval Research. *Studies of Mathematical Models of Visual Performance Capability*, by James L. Harris, Scripps Visibility Laboratory. Washington, D.C., ONR, January 1963. (Report 1, publication UNCLASSIFIED.)

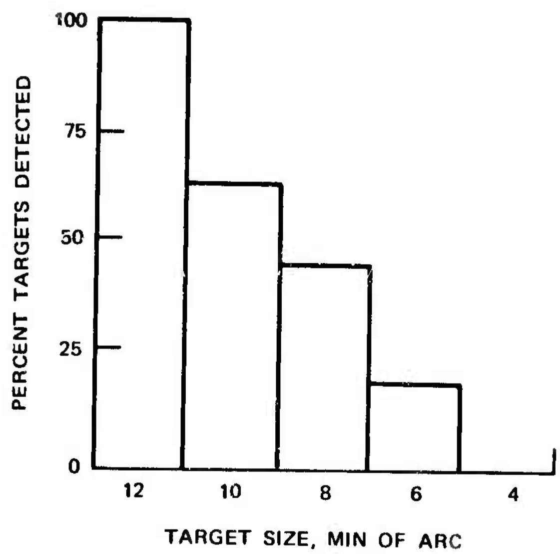

FIGURE 4. Data Shown in Figure 3 Corrected for Guessing (Assumed Chance Level = 10%).

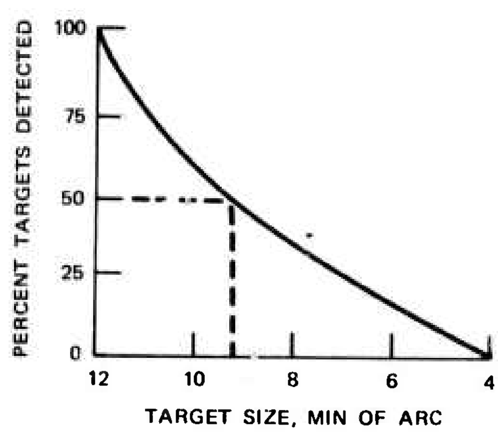

FIGURE 5. Percent Targets Detected as a Function of Target Size, Corrected for Guessing, Assuming Continuous Function.

"It is found, upon plotting many hundreds of such stimulus presentations, that the probability of target detection rises with stimulus magnitude in accordance with an ogive curve which is well fitted by a normal Gaussian integral. Statistically, the best determined point of the ogive is the point of inflection, i.e., where the probability of correct discrimination is 0.50, and this is the value of threshold contrast of prime interest in laboratory studies."[4]

An example of such summary data (which is usually the only data that is published) is shown in Figure 6.[5]

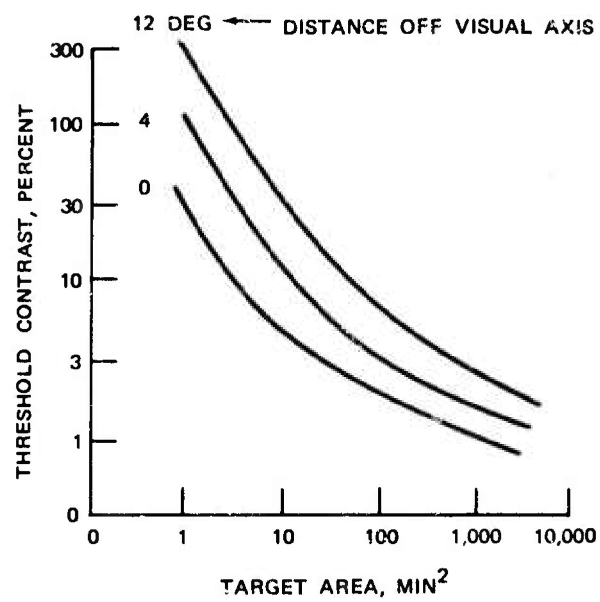

FIGURE 6. Threshold Contrast (50% Correct Detection) for Circular Targets Against a Background Luminance of 75 ftL With a 1/3-sec Viewing Time.

[4] Taylor, John H. "Use of Visual Performance Data in Visibility Prediction," APPL OPT, Vol. 3, No. 5 (May 1964), p. 562.

[5] Blackwell, Richard H., and John H. Taylor. "Survey of Laboratory Studies of Visual Detection," unclassified paper presented at the NATO Seminar on Detection, Recognition, and Identification of Line-of-Sight Targets, held at The Hague, Netherlands, 25-29 August 1969.

USING LABORATORY DATA IN A MODEL OF THE REAL WORLD

There are many differences between the laboratory test conditions and those usually encountered in operational flight. Application of such laboratory data to mathematical models of field situations can produce erroneous results for at least two reasons:

1. The accuracy of the model's description of the visual search process is not known. Assumptions are usually made (e.g., type of scan pattern), which are pure speculation.

2. The situation in which the laboratory data were collected usually was not at all similar to the situation being modeled.

The first inadequacy can be improved by collecting flight data (e.g., photographs by the pilot) to better describe the process. Performance data can also be collected during such tests. The second inadequacy is *corrected* empirically by applying fudge factors to the laboratory data. An example of the process is taken from Taylor's discussion (see Footnote 4).

> "At this point, it is well to give an example of how a field factor is determined for a real case, and how it may be used to arrive at a realistic estimate of observer performance under field conditions. Let it be assumed that an observer must confidently detect the occurrence of a stimulus of known duration and size but of unknown location within a circular display area with a diameter of 8°. The target will be present at infrequent intervals, say once every 15 min or so, and he can be allowed to miss only 5% of the occurrences. He is new to the task, and our problem is to arrange the contrast of the target so that this 95% criterion will be met. We begin by consulting the laboratory data, which tell us that, for our target size and duration and for the prevailing adapting luminance, the required contrast for 50% correct discrimination by practiced observers in a forced-choice experiment was found to be 0.0061. To correct, respectively, for confidence level, unknown location, vigilance, and lack of training we multiply this contrast value by 1.64, 1.31, 1.19, and 2.00, i.e., by 5.12. The needed target contrast, therefore, is 0.031 for our problem.

"It should be noted that this estimate refers to the 0.95 confidence level in forced-choice terms. An additional factor of 1.2 in contrast may be used to approximate ordinary seeing. It is often necessary to use laboratory threshold data from 'yes-no' experiments; in this case, a rough rule of thumb is sometimes used which calls for doubling the liminal contrast value.

"Additional contributions to the field factor may occasionally occur. These tend to be even more highly individual, and generally derive from specific environmental conditions and observer states, e.g., oxygen deprivation, dietary factors, acceleration, vibration, fatigue, distraction, toxic atmosphere, glare, anxiety, sensory deprivation, abnormal thermal levels, and a host of others. Only fragmentary data can be adduced in most cases, and it is commonly found necessary to assess these effects by means of specific experiments."

An error analysis performed as part of the development of a mathematical model of the visual detection process is rare. The discussion by Taylor quoted previously gives some indication of how many sources of error are just in the *field factor*.

THE TOTAL PICTURE

It is useful to derive a model or concept of how *all* air-to-air sightings can be described. The whole world or, as the staticians say, the "total population" consists of the results from all the actual encounters. Of course, these results are not known since (a) as they occur, the data are not recorded properly; and (b) those of interest are in the future. This total population can be *estimated* with a mathematical model, a laboratory simulation, and/or flight test simulations. The accuracy of such an estimate will directly affect the validity of the analysis leading to weapon system specification.

The basic data describing performance were shown previously in Figure 1. The spread in the reported ranges for the same pilot and the same environment has been attributed to variation of the pilot's characteristics (motivation, alertness, and sensitivity) from time to time, and to the existence of a random component in the visual search process. The spread is commonly found in experiments and is also found in decision theory models.

Performance differences between pilots will result in a range of performance curves similar to Figure 2 for each situation (Figure 7a). These curves can be combined across pilots to give a summary measure of performance *for a given set* of environmental conditions (Figure 7b).

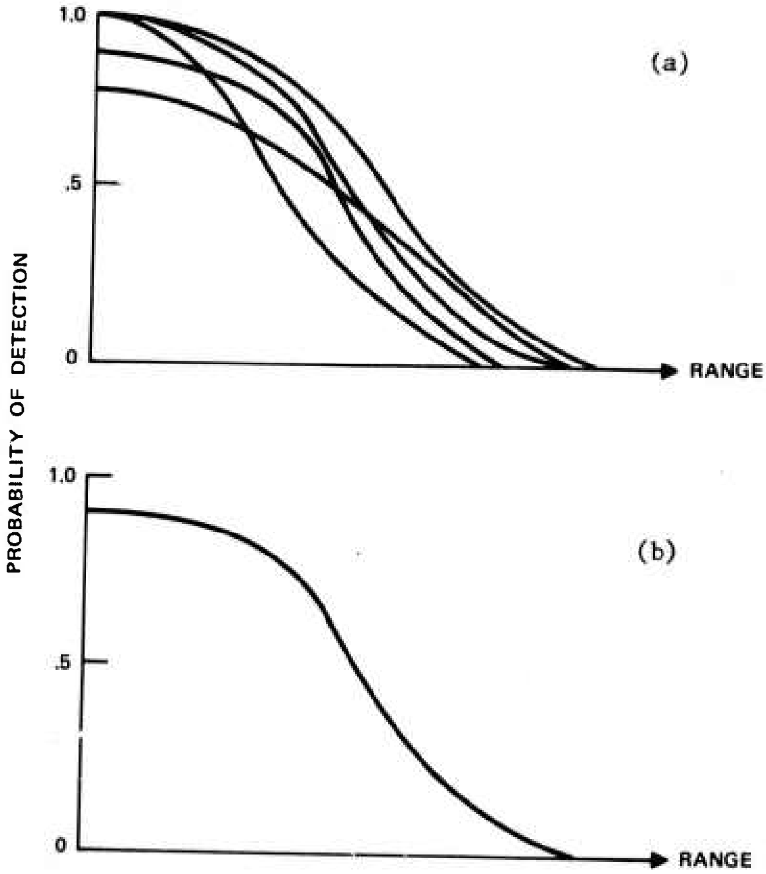

FIGURE 7. Performance Curves: (a) for Individual Pilots; (b) Summary Curve for the Group for a Given Situation.

The total population of performances (Figure 8) might be described by a number of the types of curves shown in Figure 7. Any one curve describes performance for a particular set of environmental conditions, or for a number of sets of conditions. The curves are summary curves, each based upon sets of interacting variables and, therefore, are not directly comparable with respect to individual variables, e.g., performance against a large, low-contrast target may be the same as that against a smaller, higher contrast target. The boundary curves in Figure 8 are tied to the real world by the following two statements:

Curve A might be detection of a large, high-contrast target in a clear atmosphere when the pilot knows when and where to look.

Curve B might be detection of a small, low-contrast target when the pilot's expectation of an encounter is low and the target can appear anywhere.

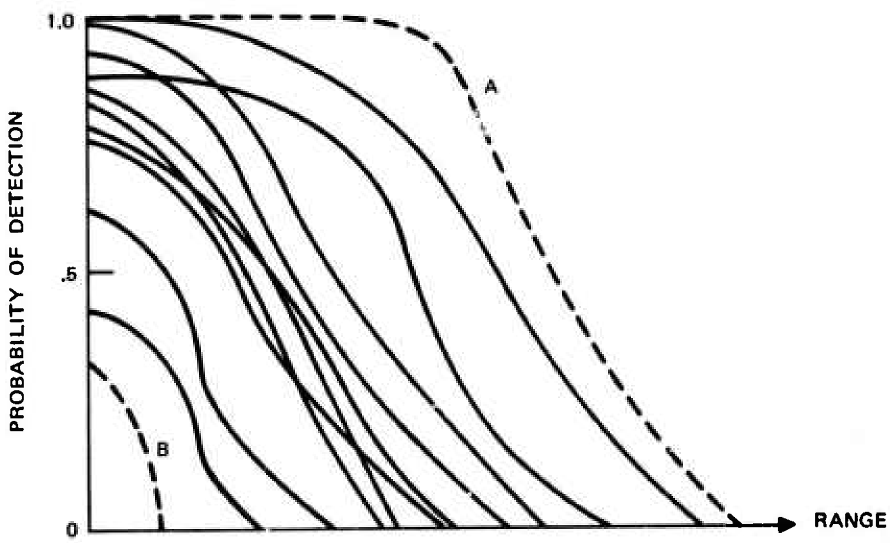

FIGURE 8. Total Population of Performance.

PROBABILITY OF OCCURRENCE

Establishment of all the probable sets of environmental conditions and determination of the performance curve for each have still not adequately described the total population. The probability of occurrence of each curve is also required. A three-dimensional plot of Figure 8 with the probability of occurrence added as the third dimension is shown in Figure 9. (Figure 8 is the horizontal plane of Figure 9.)

Figure 8 illustrates that the performance curves are not expected to occur with a uniform density in the P_D/R plane. Hence, Figure 9 may be considered to be a solid, but one whose density (number of performance curves per unit P_D x R area) is variable.

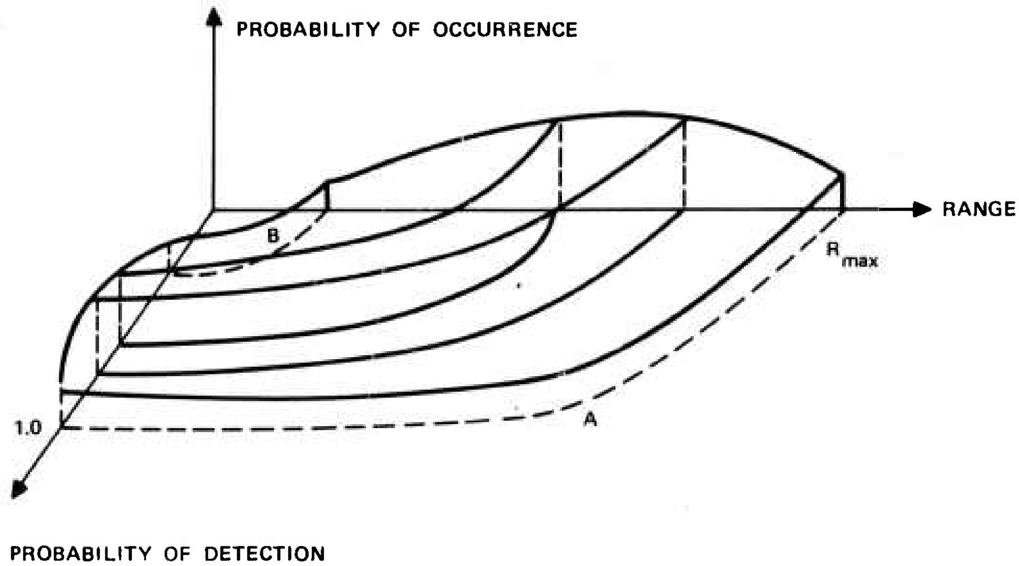

FIGURE 9. Probability of Occurrence/Probability of Detection as a Function of Range.

PERFORMANCE OF THE TOTAL POPULATION

The integral of the solid shown in Figure 9 (with density included as a fourth variable) can be normalized to a *mass* of one to describe the total population of encounters where detection occurred (Eq. 2).

$$D_{total} = \int_{R_{max}}^{o} P_D \times P_{occ} \times \text{Density} \times dR \qquad (2)$$

The plot of this normalized integral as a function of R shows the percent of all detections (under all conditions to be encountered by all pilots) that can be expected to occur by range R (Figure 10) where R varies from R_{max} to zero. An analyst could use this plot to select a missile range that would include any desired percent of the expected detections.

QUANTITATIVE ESTIMATES

An estimate of the shape and magnitude of the summary curve (Figure 10) can be obtained (1) by modeling with laboratory data as inputs, (2) by simulation, (3) by flight tests, or (4) from operational data. Comments on these four methods are given in Table 1.

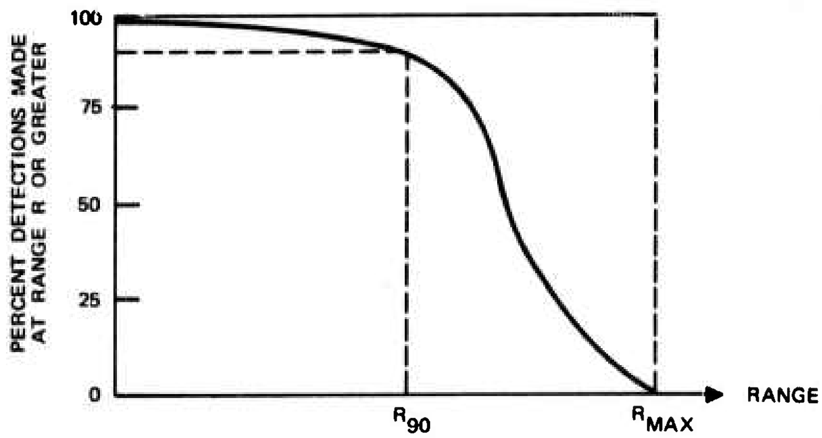

FIGURE 10. Cumulative Detections.

TABLE 1. Methods of Obtaining Visual Detection Estimates.

Mathematical modeling	Simulation	Flight tests	Operational data
1. The process to be modeled is not well known (scan pattern, accommodation, etc.).	1. The fidelity of simulation can greatly affect the results.	1. Flight tests are expensive, each trial (opportunity to detect a target) must be an actual flight in real time with one subject.	1. Data collected in the actual operational situation are usually inaccurate because available recording equipment is limited.
2. Input data from laboratory studies were gathered under conditions quite different from the operational situation.	2. Determining the level of fidelity required is often difficult.	2. Conditions are almost never exactly repeatable. Weather, pilot availability, and aircraft condition vary from day to day. A strict, balanced experimented design (e.g., order of presentation of conditions counterbalanced, pilot experience homogeneous, etc.) is usually impossible.	2. Conditions in the environment cannot be determined; *ground truth* or *air truth* is difficult or impossible to establish.
3. *Adjustment*, *field*, or *fudge* factors taking comment 2 into account are not known.	3. A simulator facility can be quite expensive.	3. The number of trials and subjects is severely limited. A large data sample is hard to obtain. The range of conditions that can be investigated is limited.	3. The data describe only part of the performance; missing data must be assumed. The data must therefore be properly interpreted, although not to the extent required of calculated, simulator, or flight test data.
4. Other inputs (e.g., probability of a set of conditions occurring) must also be estimated; and accuracy of estimate is unknown.	4. The number of conditions to be investigated is limited--but still much larger than that possible in flight.	4. The flight test data must be analyzed and interpreted (e.g., performance must be weighted by expected probability of occurrence).	4. The data do not resemble calculated, simulator, or flight test data, in that experimental design and control is completely lacking.
5. Because of 1 through 4, the validity of model results is usually unknown.	5. Simulator data require careful analysis and interpretation; e.g., performance must be weighted by expected probability of occurrence.	5. A flight test includes many of the effects encountered in the actual operational situation. Aircraft control requirements, vibration, motion, lighting, fatigue, etc., can operate to make the flight test a "high-quality simulation," *if planned properly*.	5. The data, although possibly inaccurate, are *real*, although distortions of reality are still possible. No extrapolations or fudge factors are necessary.
6. Model results should be validated by flight tests.	6. Simulations can allow the task to be performed in toto with interactions present.		
7. Modeling can cover a much larger range of conditions and parameter variations than can simulation or flight testing.	7. Variables can be closely controlled, and trials can be repeated (repeated measurements) so that sufficient data can be collected to allow meaningful statistical analysis.		
8. Modeling structures the phenomenon and relates the effect to its causes.	8. Simulator results should be validated by flight tests.		

MATHEMATICAL MODEL FOR AIR-TO-AIR TARGET DETECTION

This section presents a mathematical model for the probability of visual target detection. Such a model is useful in understanding the visual detection process, interpreting field data, and structuring flight tests. The prediction is given in the form of cumulative probability of detection as a function of range, i.e., the probability that the aircrewman will have detected the target by the time it has reached a given range.

The probability curve can be computed in numerous ways. After a literature search, it was decided to use the method based on the visual detection lobe as discussed by Bartell,[6] Heap,[7] and Lamar.[8]

VISUAL DETECTION LOBES

A visual detection lobe is the volume of space in front of an observer's eyes within which an object is detectable a given percent of the time (e.g., 50%). In daylight, the shape resembles a pear with the base close to the eyes (Figure 11). The pear shape is, of course, only an approximate way of describing human performance data; its circular cross section also is an approximation. Near objects may be seen at fairly large angles off the visual axis, while far objects can be seen only if looked at directly so that they are imaged on the fovea. The angle off the visual axis, θ, must be less than about 0.8 deg for the object to be imaged on the fovea. The lobe cross section is defined by the range, R, and θ. The lobe is considered to move with the eyes.

The contrast threshold is the minimum contrast that would enable an observer to see an object of a given size at a given range and angle off the visual axis. The equation given in the references in Footnotes 6, 7, and 8 for this contrast threshold is

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[6] Army Missile Test and Evaluation Directorate. *Report of Mathematical Model for the Probability of Visual Target Selection*, by Rena M. Bartell. White Sands Missile Range, New Mexico, AMTED, November 1965. (Redeye Report No. 66-16, publication UNCLASSIFIED.)

[7] Heap, E. "Mathematical Theory of Visual and Televisual Detection Lobes," J INST MATH APPL, Vol. 2 (1966), pp. 157-85.

[8] Armed Forces-Naval Research Council Committee on Vision. "Operational Background and Physical Considerations Relative to Visual Search Problems," by Edward S. Lamar, in *Proceedings of Symposium*. Washington, D.C., NRC/VIS, April 1959. (National Academy of Sciences/National Research Council, Publication 712, publication UNCLASSIFIED.)

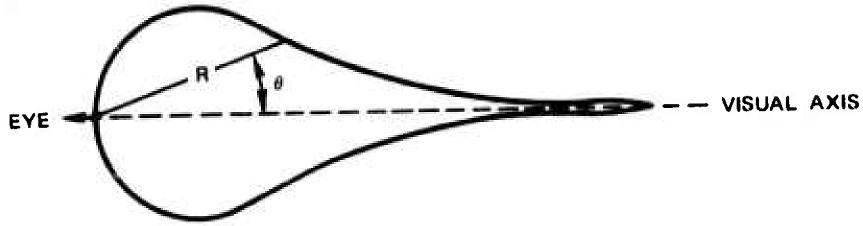

FIGURE 11. Cross Section of Detection Lobe Where R Is the Range-to-Lobe Boundary and θ Is the Angle off the Visual Axis (Dotted Line). The solid detection lobe is generated by revolving the cross section about the dotted line.

$$C = 1.75\ \theta^{1/2} + \frac{45.6\ \theta\ R^2}{A} \tag{3}$$

where

θ = angle off the visual axis in deg ($0.8 < \theta < 90$ deg)

R = range to the target in nmi

A = area (in ft^2) of the cross section of the target in the plane perpendicular to the visual axis

C = contrast of the target as seen at the eye and expressed as a percent.

The contrast, C, is given by

$$C = \frac{|L_B - L_T|}{L_B} \times 100 \text{ (in \%)} \tag{4}$$

where

L_B = luminance of the background

L_T = luminance of the target.

If there is haze in the air, the contrast as seen at the eye is a function of the intrinsic contrast of the target, C_o, and the meteorological visibility. At fairly high altitude where there is little or no haze, C as seen at the eye will be equal to the intrinsic contrast, C_o, where

$$C_o = 1.75\ \theta^{1/2} + \frac{45.6\ \theta\ R^2}{A} \tag{5}$$

When θ is less than 0.8 deg, the target will be imaged on the fovea, so that for $\theta < 0.8$ deg, the threshold contrast is independent of θ. Setting $\theta = 0.8$ deg in Eq. 3 gives

$$C_o = 1.57 + \frac{36.5\ R^2}{A} \tag{6}$$

The maximum range of a daylight visual detection lobe occurs when the object is imaged on the fovea. In the absence of haze, this range is called R_M and is obtained from Eq. 6

$$R_M = 0.1655\ \sqrt{(C_o - 1.565)A} \tag{7}$$

One could now theoretically compute detection lobes for the haze-free, daylight case for a target of given area and contrast by getting maximum R from Eq. 7, and then by choosing arbitrary values for R from R_M to 0 and using them in Eq. 3 to get the corresponding values of θ. However, Eq. 3 is not very conveniently solved for θ, so the following steps are taken.

First, divide Eq. 3 by Eq. 6 to eliminate A.

$$\frac{C_o - 1.75\ \theta^{1/2}}{C_o - 1.57} = 1.25\ \theta \left(\frac{R}{R_M}\right)^2 \tag{8}$$

From this equation, two new variables, F and G are defined (refer to Footnote 7).

$$F = \frac{0.49\left(\frac{R_M}{R}\right)^4}{(C_o - 1.565)^2} \tag{9}$$

$$C = \frac{0.8\ C_o \frac{R_M}{R}^2}{C_o - 1.565} \tag{10}$$

Then

$$\theta = F\left(\sqrt{G/F + 1} - 1\right)^2 \qquad (11)$$

Figure 12 shows a detection lobe computed from Eq. 11.

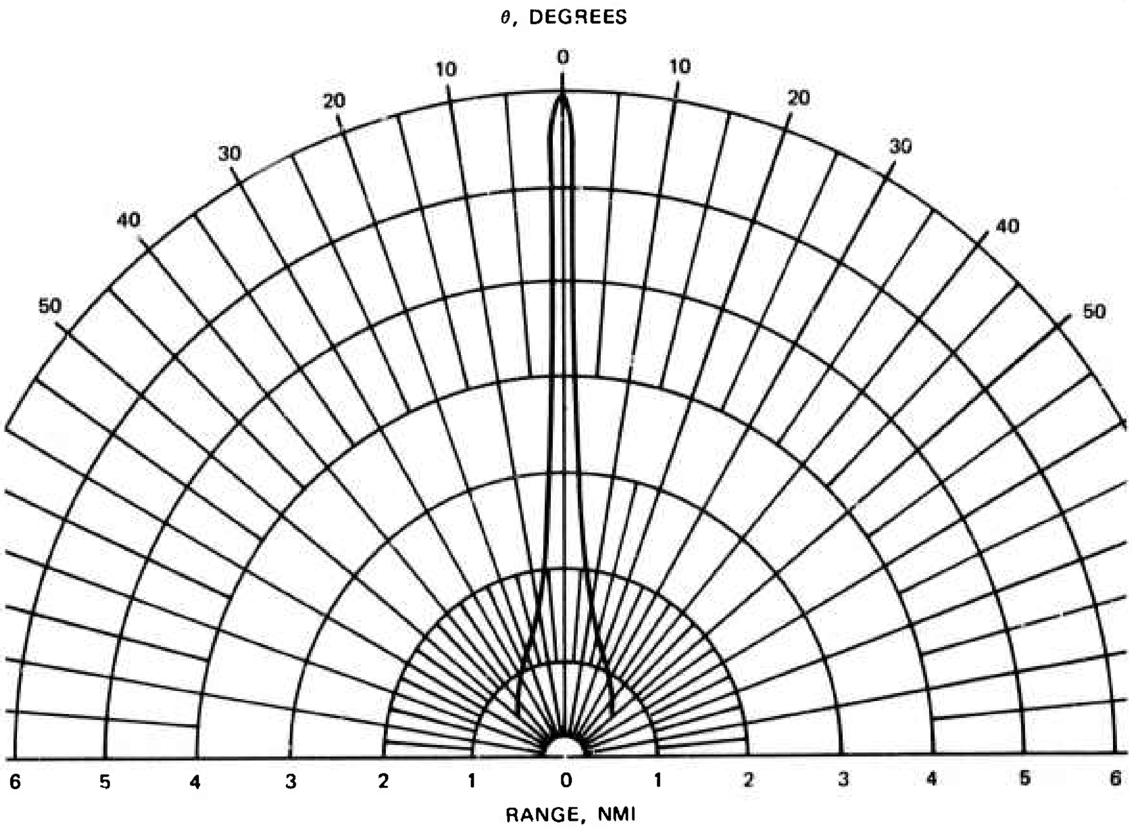

FIGURE 12. Visual Detection Lobe: Target Area = 55 ft^2; Target Contrast = 30%; No Haze.

EMPTY-FIELD MYOPIA

Several phenomena have been observed during visual search of a completely empty field. The searcher tends to become disoriented and cannot remember where he has already searched. There is almost no kinesthetic feedback from eye muscles, so the searcher does not know precisely where his eyes are aimed during any given fixation. When an object does appear in the field, it is seen suddenly and clearly, at

closer than threshold range (Whiteside,[9] and Miller and Ludvigh[10]). When searching an empty field, normal eyes come to a rest focus at a point about 5.5 ft away instead of at infinity. This means that the person with normal vision is effectively nearsighted and requires objects to be closer to him than he would in a structured field. Slightly farsighted eyes will focus at infinity even with nothing to focus on. Whiteside found that, in an empty field, the test object had to subtend about twice the angle at the eye in order to be seen; that is, it had to be twice as large or twice as close. Kraft found that, for an 80% detection level, a target in a dark, empty visual field had to be about 1.5 times brighter than one in a field with a simulated city in the distance.[11]

In high-altitude air-to-air search, in the absence of broken clouds and when the target is above the horizon, the empty-field situation prevails. Therefore, the maximum range at which an observer might be expected to see a target must be shortened. Returning to Eq. 7 for maximum range, if the target is required to be at half the range for a given area, A, for the empty-field situation, Eq. 7 is rewritten

$$R_M = \frac{0.1655}{2} \sqrt{(C_o - 1.565)A} \qquad (12)$$

It is not certain that shortening the maximum range is the only effect of empty-field myopia, but there is not enough information available to estimate what other effects might be present. Figure 13 is an example of the lobe shown in Figure 12 shortened for empty-field myopia.

DETECTION PROBABILITY

The mathematical model assumes that the observer will see the target if it is within his detection lobe. There will be observers who will see the target outside the computed lobe or will not see one inside the lobe. This concept of a "soft-shell" lobe has been further developed and used by Seyb in the development of a mathematical model of visual detection.[12] The model predicts the *average* performance of many observers searching for many targets.

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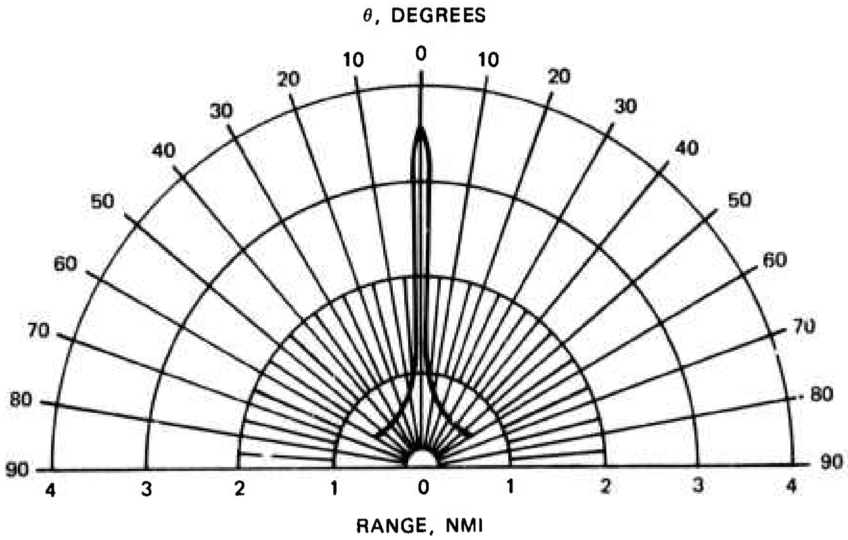

FIGURE 13. Visual Detection Lobe Corrected for Empty-Field Myopia: Target Area = 55 ft^2; No Haze; Target Contrast = 30%.

The probability that the observer will see the target in one glance is the probability that the target is in the lobe during that glance. Figure 14 shows the azimuth and elevation search geometry. Once the target is within the maximum range, the probability that the target will be within the lobe is the ratio of the solid angle covered by the lobe to the total angle that must be searched. This single-glimpse probability, g, is given in Eq. 13

$$g = \frac{\theta^2}{(H+\theta)\ (\phi+\theta)} \tag{13}$$

where

$2H$ = azimuth angle about the visual axis that must be searched

2ϕ = elevation angle about the visual axis that must be searched

2θ = width of the detection lobe at the range of the target.

Table 2 shows an effect of search-sector size on glimpse probability. When a person is searching, he will change the direction of his glance about every 1.6 sec (Lamar, Footnote 8). During this time the range to the target will have changed, so a new "g" must be computed using the θ

corresponding to the new range. If one assumes that each glimpse is an independent event (and there is precedent for doing so, see Footnote 6) and numbers them 1, 2,...n, then he can write the expression for the cumulative probability that the target will be seen by the time it is at R_n. Since for independent events the failure probabilities multiply, the probability of success, P_n, is given by

$$P_n = 1 - \prod_{i=1}^{n} (1 - g_i) \tag{14}$$

where

$\prod_{i=1}^{n} (1 - g_i)$ = product of the probabilities of not seeing the target by the nth glimpse.

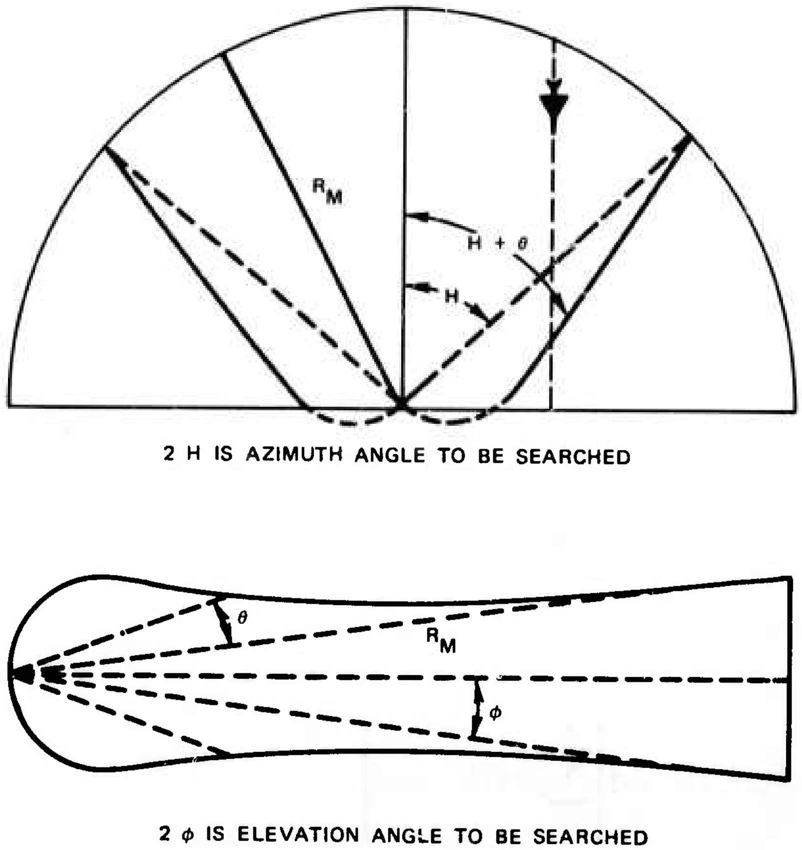

FIGURE 14. Azimuth and Elevation Search Geometry.

TABLE 2. Detection Lobe and Glimpse Probabilities.

R, n.mi	θ, deg	g for H = ±90 deg φ = ±30 deg	g for H = ±90 deg φ = ±15 deg
0.6	50	0.2218	0.2733
1.3	16	.0533	.0789
2.0	8	.0166	.0275
2.6	5	.0065	.0115
3.3	3	.0030	.0055
3.9	2	.0016	.0029
4.6	2	.0009	.0017
5.2	1	.0005	.0010
5.9	1	.0003	.0007
6.5	1	0.0002	0.0005

A more convenient form of P_n is derived in Eq. 15-17.

$$\ln(1 - P_n) = \ln \sum_{i=1}^{n} (1 - g_i) = \sum_{i=1}^{n} \ln(1 - g_i) \tag{15}$$

Then

$$1 - P_n = \exp\left[\sum_{1}^{n} \ln(1 - g_i)\right] \tag{16}$$

and, finally,

$$P_n = 1 - \exp\left[\sum_{1}^{n} \ln(1 - g_i)\right] \tag{17}$$

If the first glimpse, g_1, is taken at the edge of the maximum range circle, g_1 is a function of R_M since the θ for the g_1 depends on R_M. g_2 is then a function of $(R_M - \Delta R)$ where ΔR is the change in range that takes place during one glimpse. In like manner,

$$g_3 = f(R_M - 2\Delta R),\ g_4 = f(R_M - 3\Delta R),\ \text{etc.} \tag{18}$$

Actually, the first glimpse may occur any time from R_M to $(R_M - \Delta R)$, so the probability of detecting the target from R_M to $(R_M - \Delta R)$ is the average of g_1, and from $(R_M - \Delta R)$ to $(R_M - 2\Delta R)$ the average of g_2, etc. Therefore, one needs the average of each of the failure probability terms in Eq. 18. For the first glimpse,

$$\ln(1 - g_1) = 1/\Delta R \int_{R_M-\Delta}^{R_M} \ln(1 - g_i)\ dR \tag{19}$$

If we write such an integral for each g_i and sum them, all the integrals are of the same form with the lower limit of one corresponding to the upper limit of the next. The whole series summation can be written

$$\sum_{i=1}^{n} \ln(1 - g_i) = 1/\Delta R \int_{R}^{R_M} \ln(1 - g_i)\ dR \tag{20}$$

and

$$P_N = 1 - \exp\left[1/\Delta R \int_{R}^{R_M} \ln(1 - g_i)\ dR\right] \tag{21}$$

Figure 15 is an example of a cumulative probability of detection curve; it was computed from the lobe shown in Figure 13. The glimpse probabilities were computed for an azimuth search angle of ±90 deg and an elevation search angle of ±30 deg. The integral in Eq. 17 was then evaluated numerically using Simpson's Rule. ΔR is the change in range during one glimpse. For a target traveling a radial path, either to or from the observer,

$$\Delta R = (\text{equivalent velocity})\ T$$

where T is the time required for one glimpse and is generally agreed in the literature to be 1.65 sec. The equivalent velocity is the combination of the target and observer's velocity and for the curve in Figure 15 was taken to be 400 knots, so

$$\Delta R = 0.181 \text{ nmi}$$

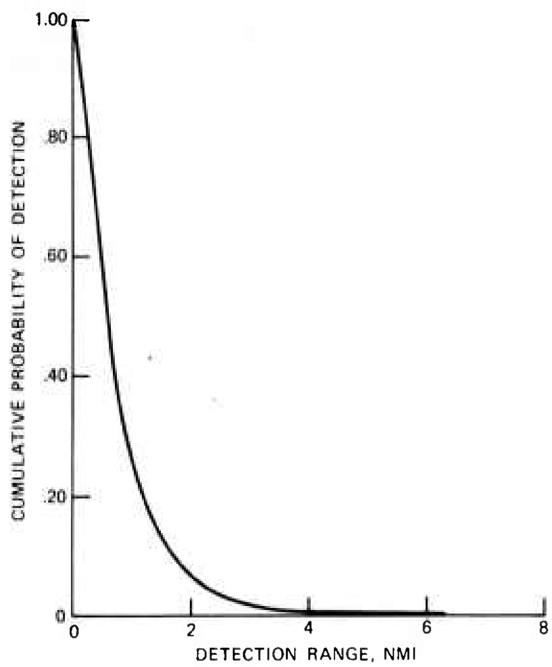

FIGURE 15. Cumulative Probability of Detection for a Target Moving on a Radial Path to or From an Observer (Azimuth Angle Searched = ±90 deg; Elevation Angle Searched = ±30 deg).

Figure 15 is the end product of this visual-detection model. Considerably more analysis is required using such individual sighting curves to generate the summary curve discussed earlier in this report (Figure 10) that is required by the systems analyst for use in selecting missile range requirements.

SUMMARY

This report describes the types of visual detection data that come from field tests and laboratory psychophysical experiments. Differences between the two situations and the danger in using data from one to predict the other are also pointed out. The requirement for further analysis (combination of the detection data with the probability of occurrence of the situations under which it was collected) is illustrated.

A mathematical model is presented which uses the type of laboratory data and fudge factors described earlier. Sample results are shown, and it is reiterated that more analysis must be conducted before system design parameters can be derived from the data.

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